1. Lavaca Bay - Development of Freshwater Inflow/Biological Indicator Relationship

TWDB RFQ# 580-18-RFQ0068

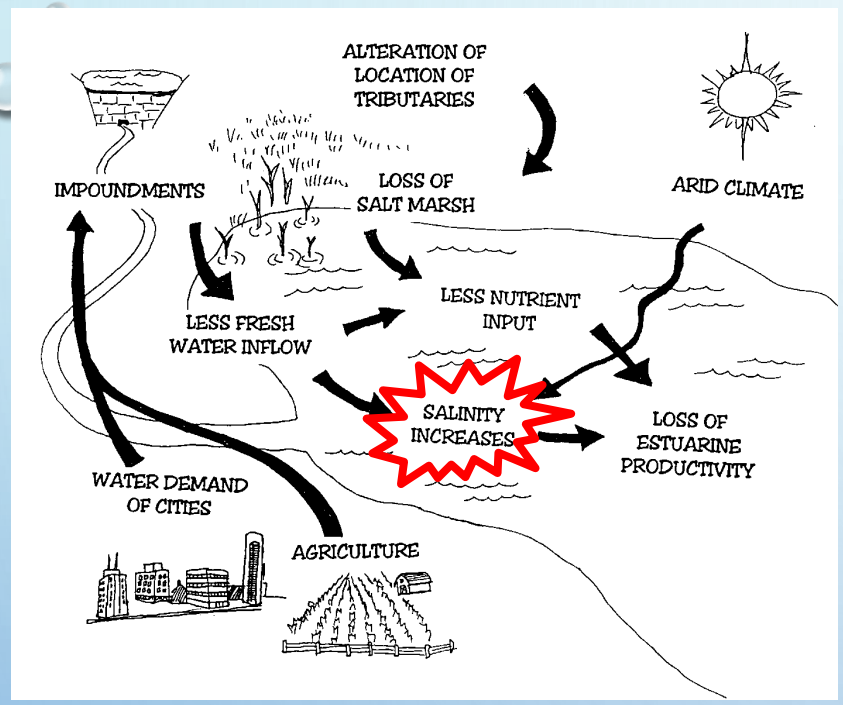
2. Using Comparative Long-term Benthic Data For Adaptive Management Of Freshwater Inflow To Three Basins

TWDB INTERAGENCY AGREEMENT # 18000122236

Paul Montagna

TEXAS A&M UNIVERSITY CORPUS CHRISTI | HARTE RESEARCH INSTITUTE FOR GULF OF MEXICO STUDIES

Approach to Link Inflow and Living Resources



Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Freshwater Inflow
- Quantity
  - Timing
  - Frequency
  - Duration
  - Extent
- Quality
- Tidal connections

Estuarine Conditions
- Salinity
- Sediment
- Dissolved material
- Particulate material

Estuarine Resources
- Integrity
  - Species composition
  - Abundance
  - Biomass
  - Diversity
- Function
  - Primary production
  - Secondary production
  - Nutrient recycling
- Sustainability
  - Habitats
  - Valued resources
  - Ecosystem services

Sources: Alber *Estuaries* (2002); Palmer et al. *Hydrobiologia* (2011); Montagna et al. *Hydrological Changes and Estuarine Dynamics* (2013)

- Inflow has indirect effects: "Domino Theory"
- Work backwards:
  - Link estuary conditions to benthic response
  - Find optimal inflow to maintain the estuary (salinity and nutrient) conditions

1. CLBBASC Work Plan Needs

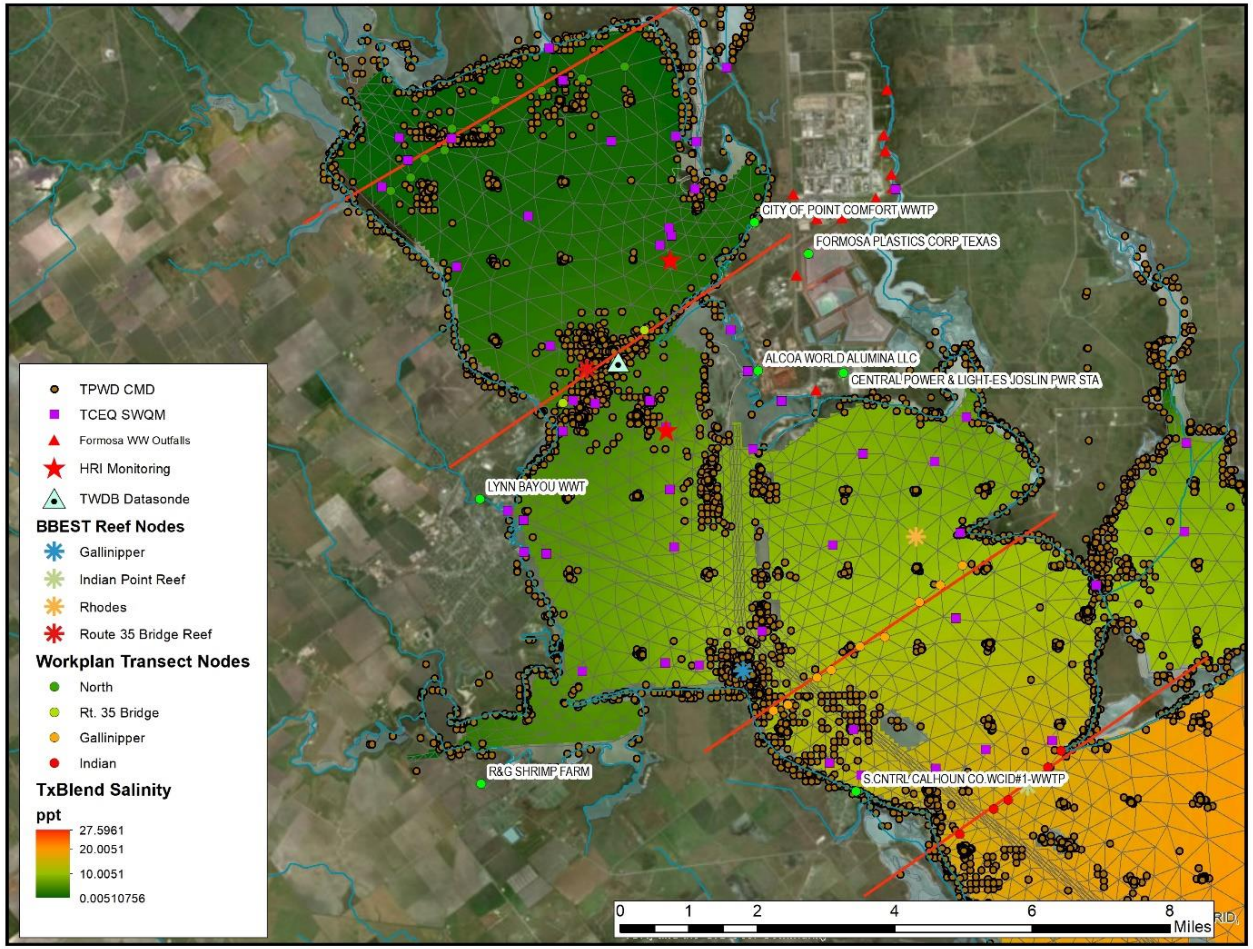
- Stakeholder needs: CLBBASC Work Plan
  - Number 12
    - Priority 1 calls for intense literature review
    - Priority 6 calls for analysis of commercially important species
    - Priority 8 calls for evaluation of achievement of MBHE recommendations
  - Number 14 calls for improvement of hydrodynamic models by ensuring input data sets are correct
- Project Purpose
  - Provide an understanding of the relationships between freshwater inflow and habitat in Lavaca Bay based on long-term monitoring data
  - Provide information for consideration by the BBASC and the TCEQ during future rulemaking related to environmental flow standards for Lavaca Bay

Lavaca Bay Tasks and Timelines

- Obtain and analyze data
  - Bioindicator identification
  - Condition identification
  - Inflow identification
  - Time series, autocorrelation, and confounding factors identification
  - Event identification
  - Linking inflow events and communities
- Reporting
  - Draft Final Report due October 31, 2019 (3 months out)
  - Final Report due December 31, 2019

Long-Term Data Sets

- TCEQ – Water quality
- TPWD – Fisheries, epibenthos, oysters
- HRI – Nutrients, salinity, DO, Chl, sediments, macroinfauna
- Formosa – Site specific on water, infauna, fish
- Alcoa, EPA, HRI, TDH – Mercury in sediments, and fish



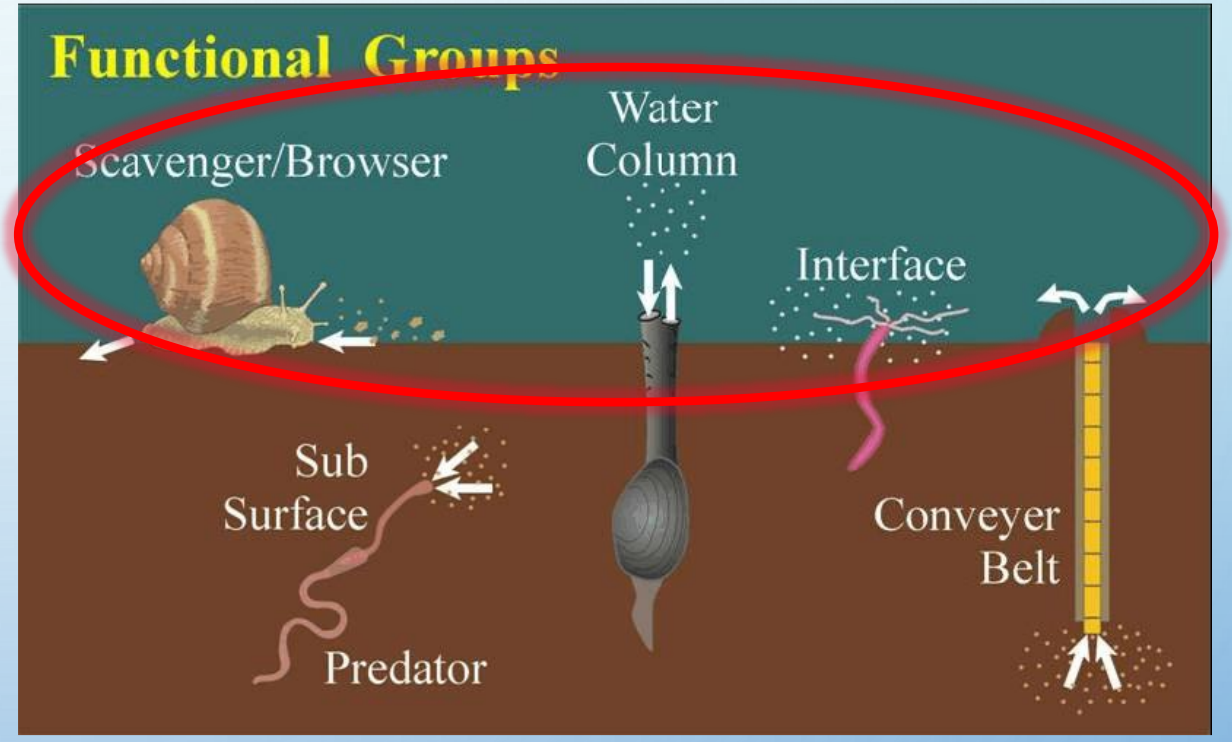
Bioindicators Used by All BBEST's

Bay System	Indicator Species
Sabine Lake, 2009	Eastern oyster, Atlantic rangia, Blue crab juveniles, Olney bulrush, Intermediate marsh, Brackish marsh
Galveston Bay, 2009	Eastern oyster, Atlantic rangia, Dermo, Oyster drill, Wild celery, Gulf menhaden, blue catfish, Mantis shrimp, Pinfish
Brazo	Salinity, Nutrients, Sediment supply
Lavac	ue
Missi Anton	ab
Nuec Bays, 2011	blue crab, Atlantic croaker, nutrient cycling, sediment loading
Lower Laguna Madre, 2012	Seagrasses

But, it's not only bivalves, it's all benthos!

Benthos are Excellent Bioindicators Because they Cannot Move

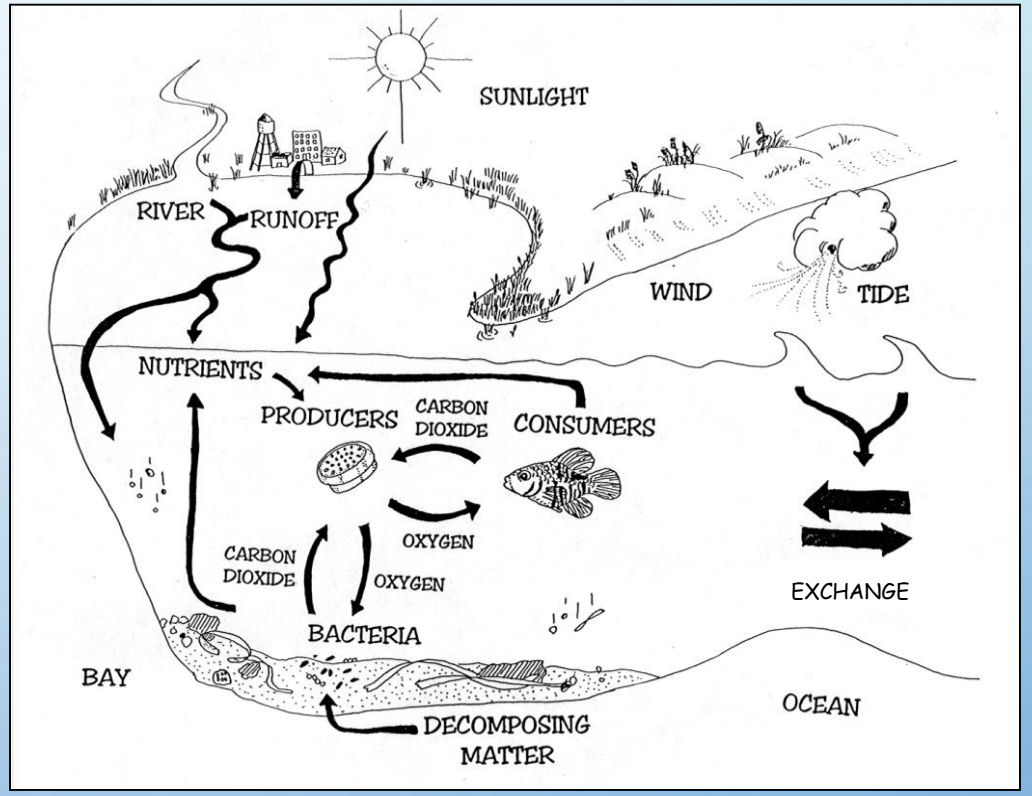
- Sessile
- Relatively long-lived
- Diverse
- Well known
- Respond to food from above



Source: Tenore, K.R. et al. (2006) *Journal of Experimental Marine Biology and Ecology* 330: 392-402.

Benthos are Excellent Bioindicators Because they are Integrators

- Sediments are the memory of the ecosystem
- Benthos affected first and most
- Thus, benthos are integrators
  - overlying water column is dynamic
  - benthos sample and integrate ephemeral events over long times scales

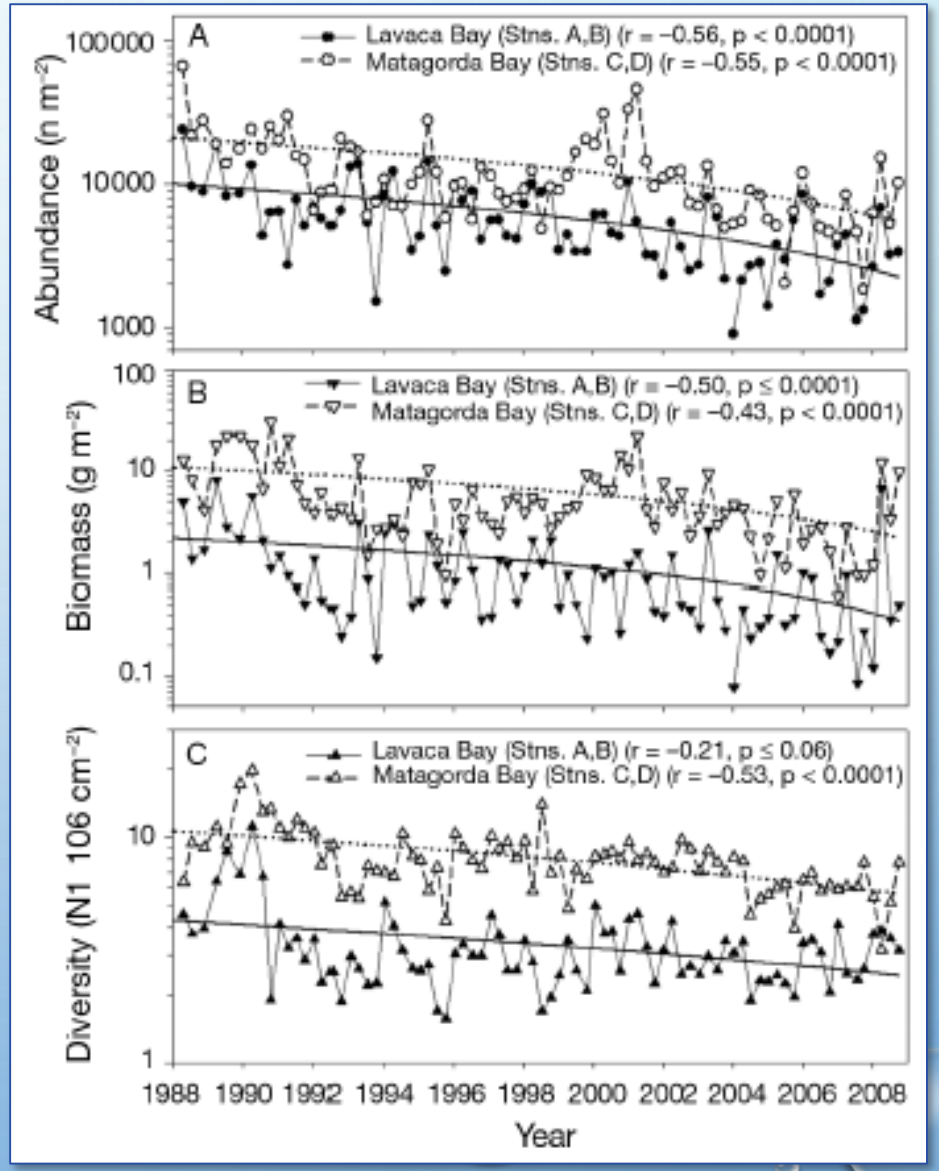


Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Some Results – Benthos

- Benthic macrofauna have been declining dramatically (> 2 orders of magnitude) over 20 years in the Lavaca and Matagorda Bays

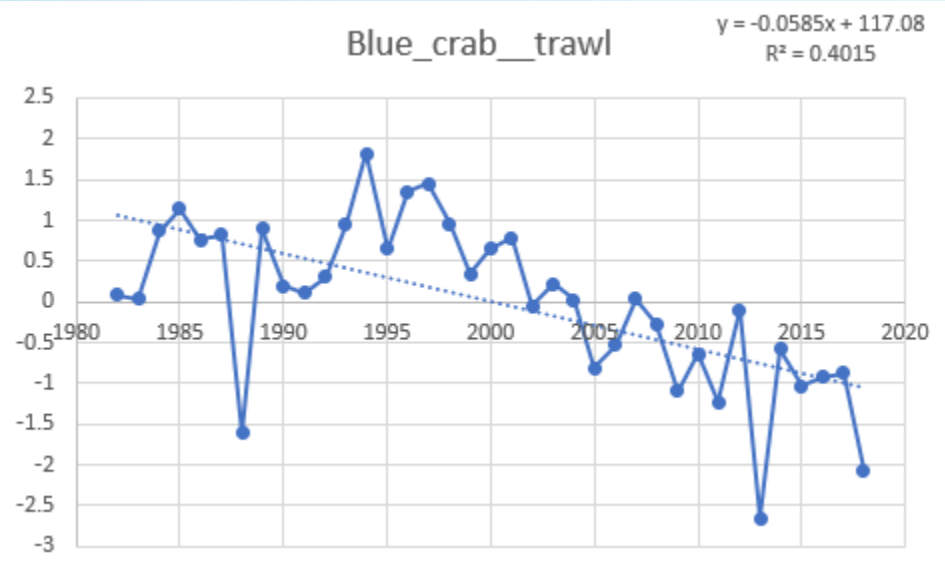
Variable	Stat	Abundance	Biomass	Diversity
Salinity	r	0.43	0.52	0.42
	p	0.04	0.01	0.05
DO	r	0.03	0.16	0.36
	p	0.88	0.49	0.09
Temperature	r	-0.29	-0.36	-0.59
	p	0.18	0.10	0.004

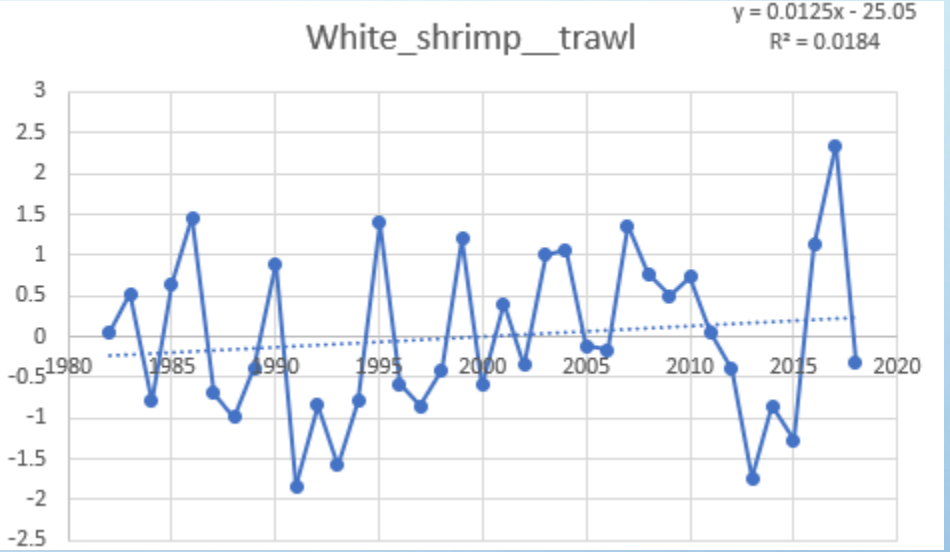


Source: Pollack et al. *Marine Ecology Progress Series* (2011)

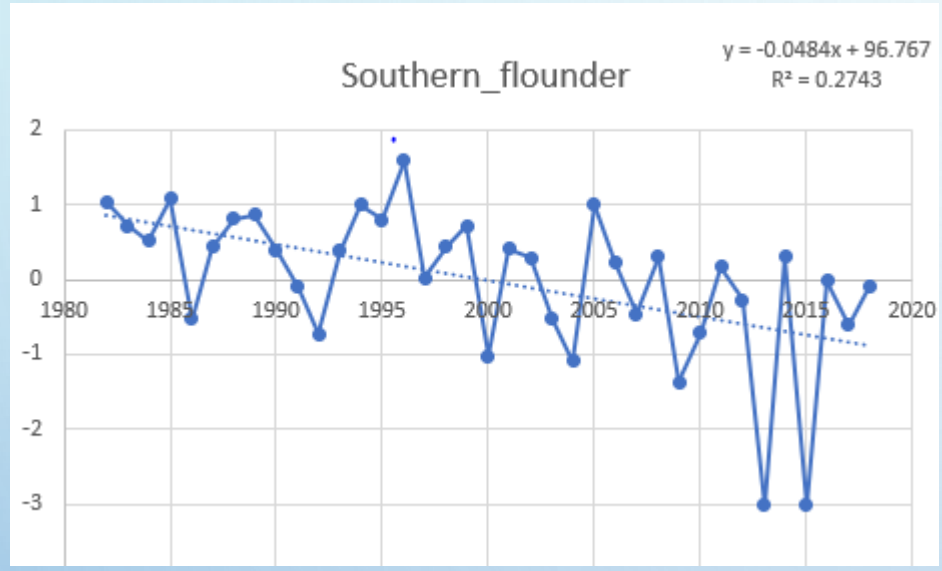
Some Results – Shellfish

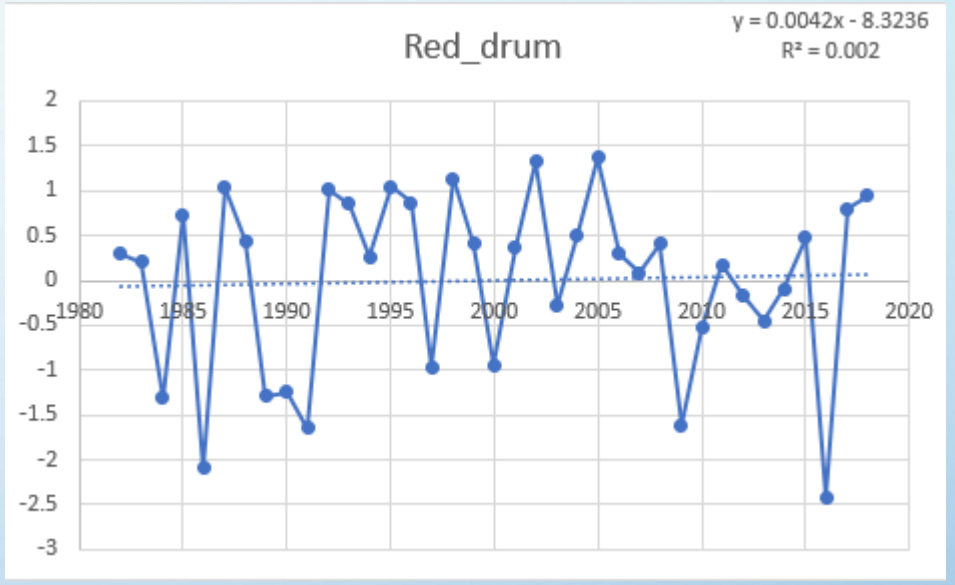
- Declines in Blue Crab,

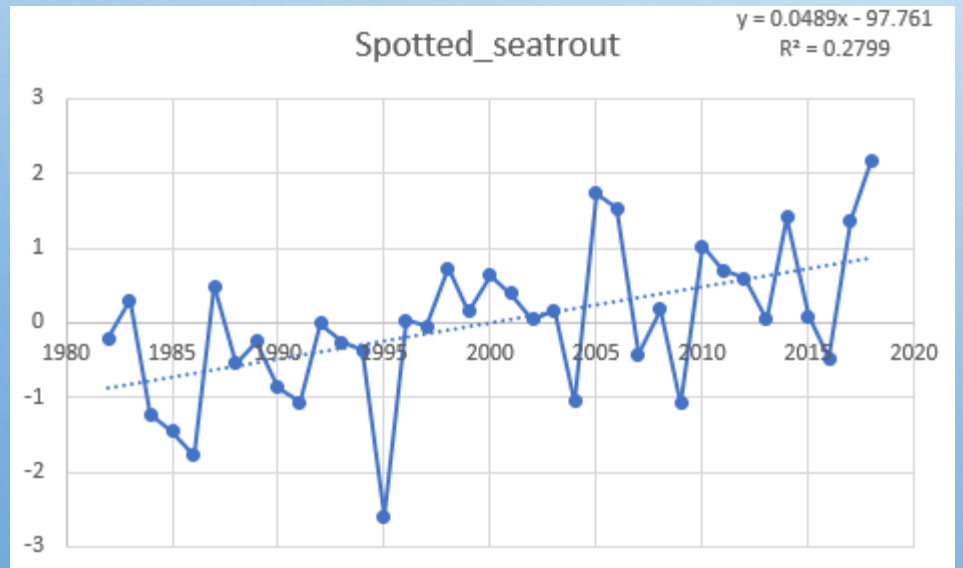


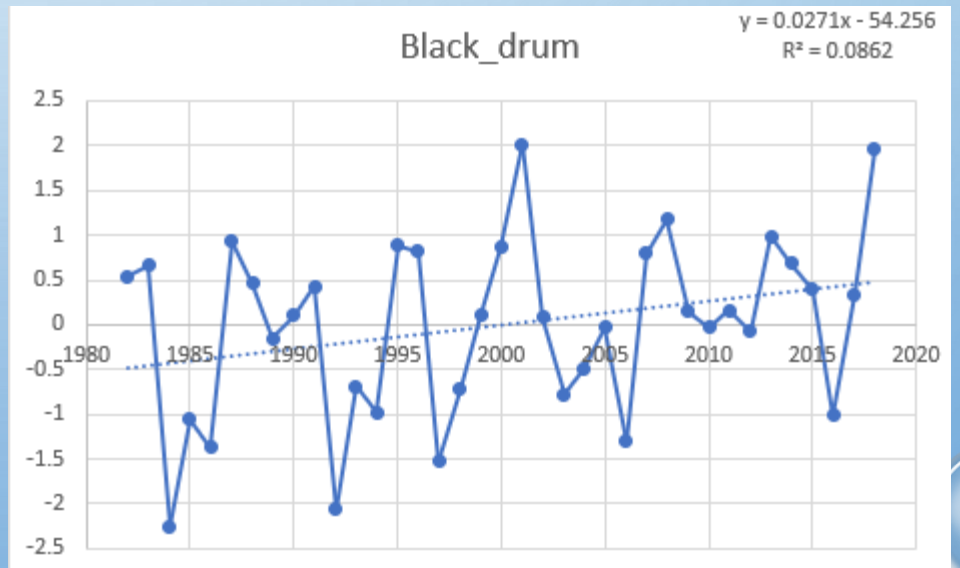


Some Results – Fish

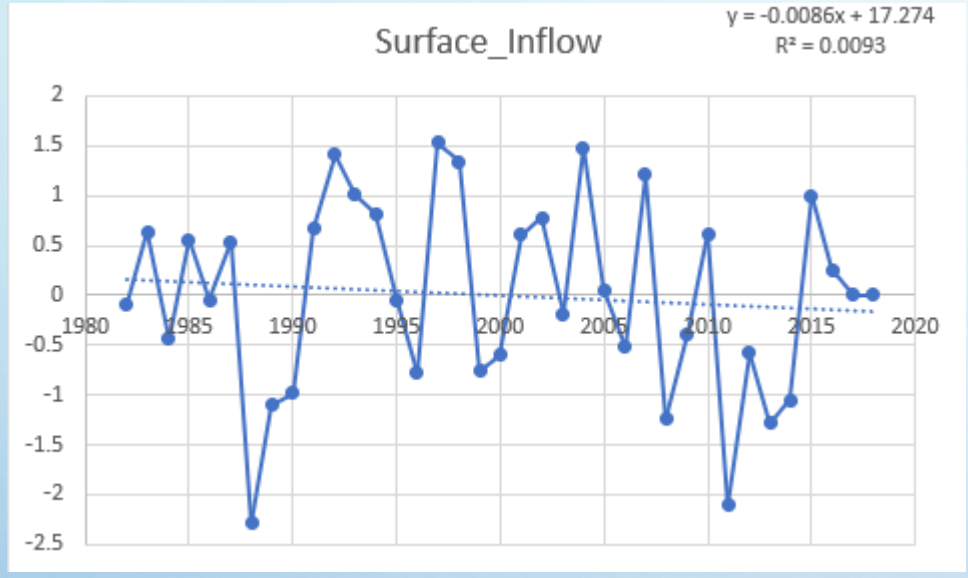


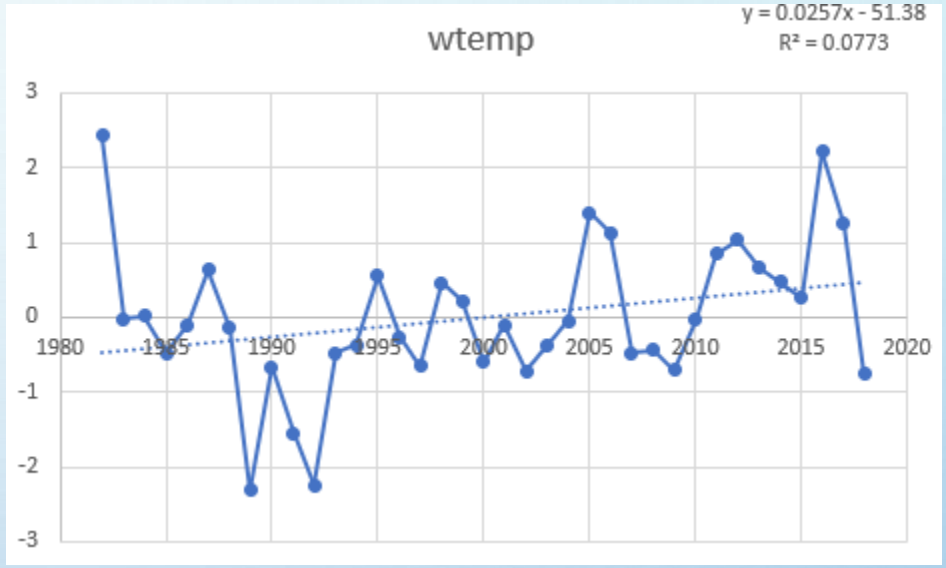


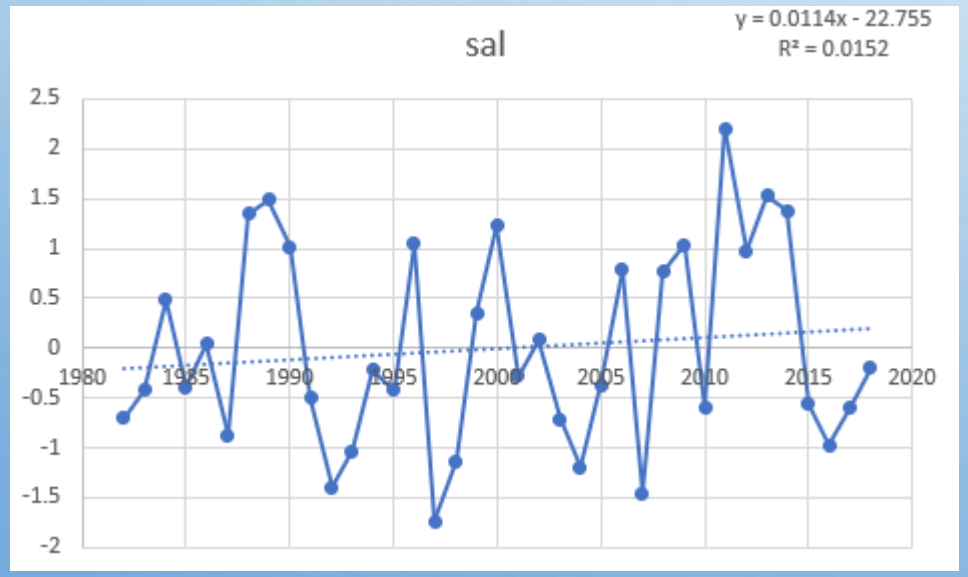


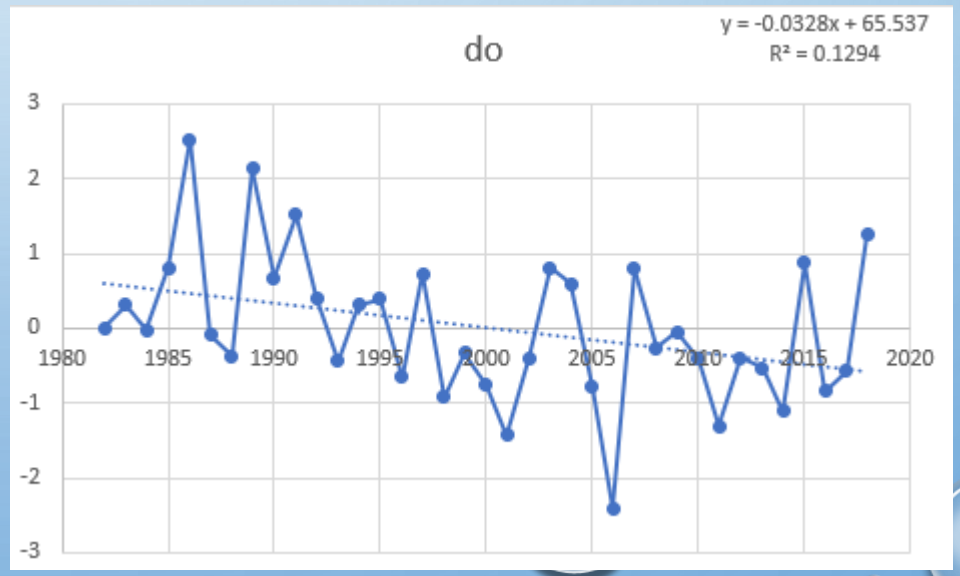


Some Results – Environmental





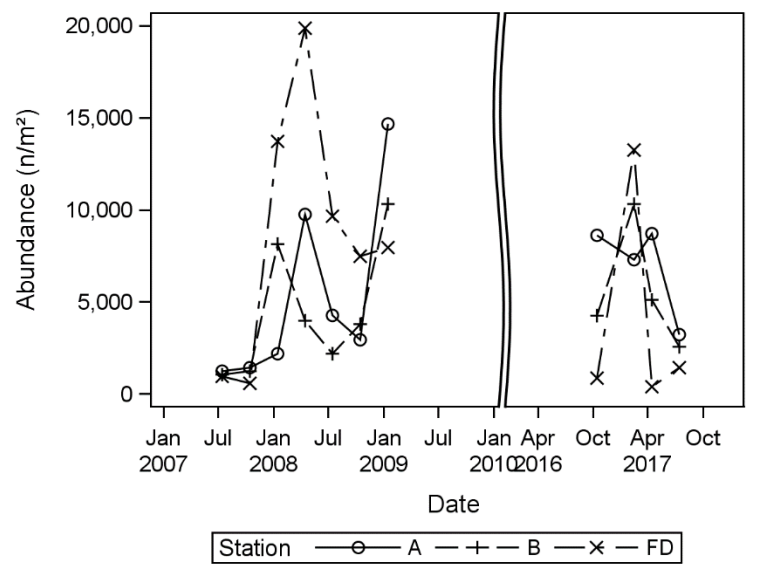




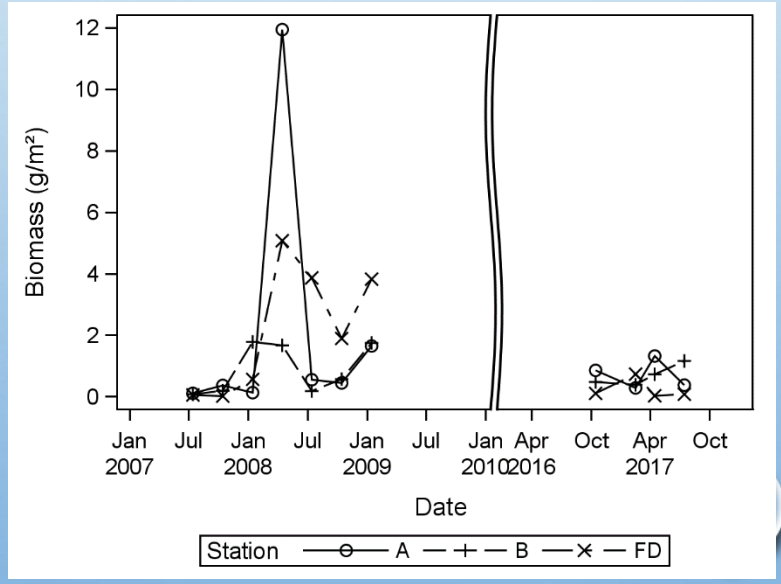
Some Results – Benthos

- Sampled a site at the Formosa Discharge (FD) from 2007-2009 and 2017
- No difference between FD and our Lavaca Bay stations A and B

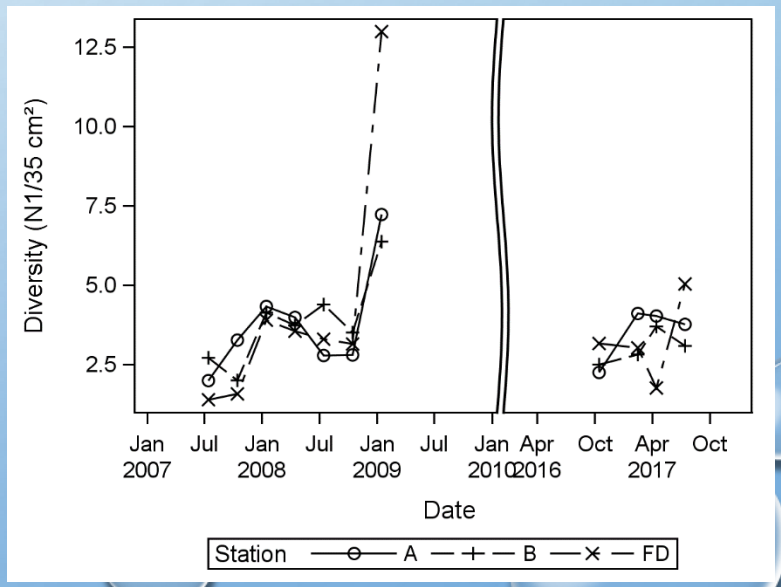
P = 0.2950



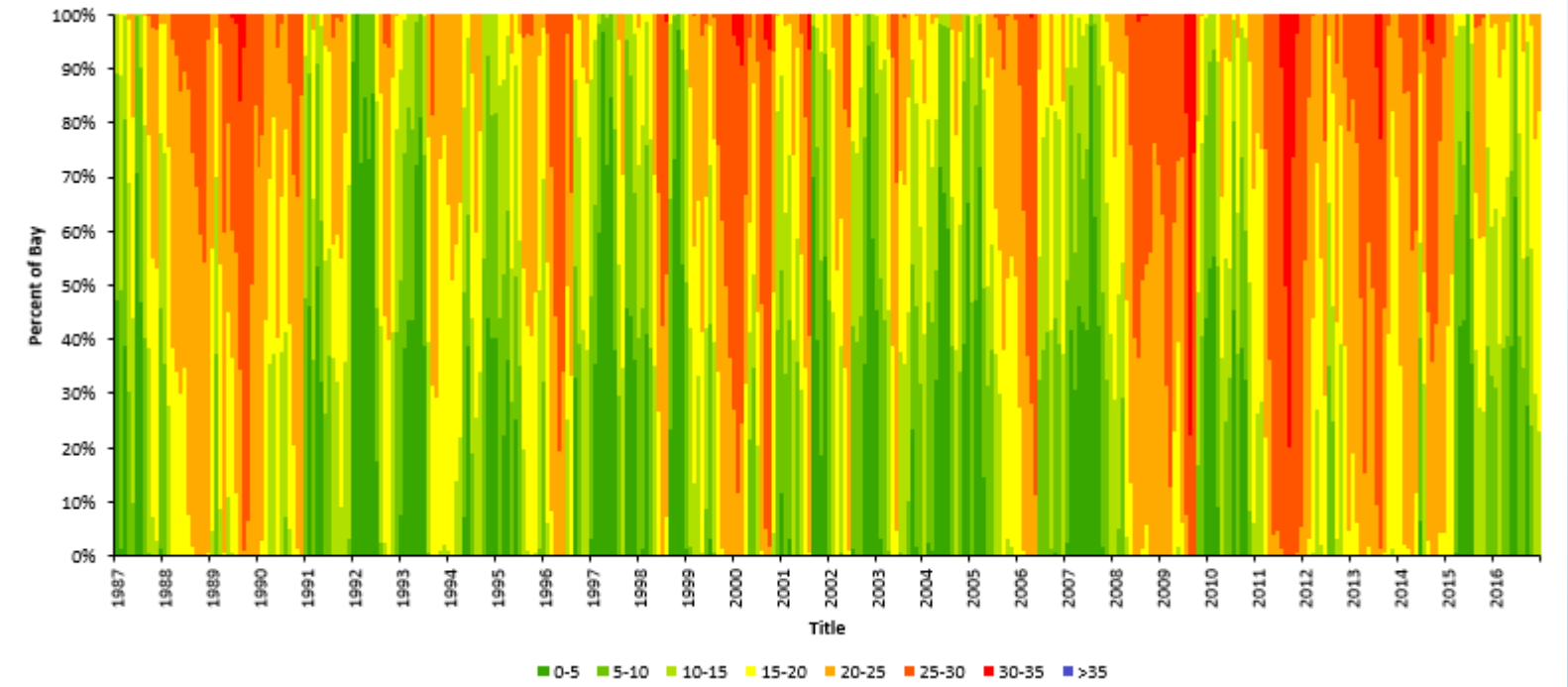
P = 0.7152

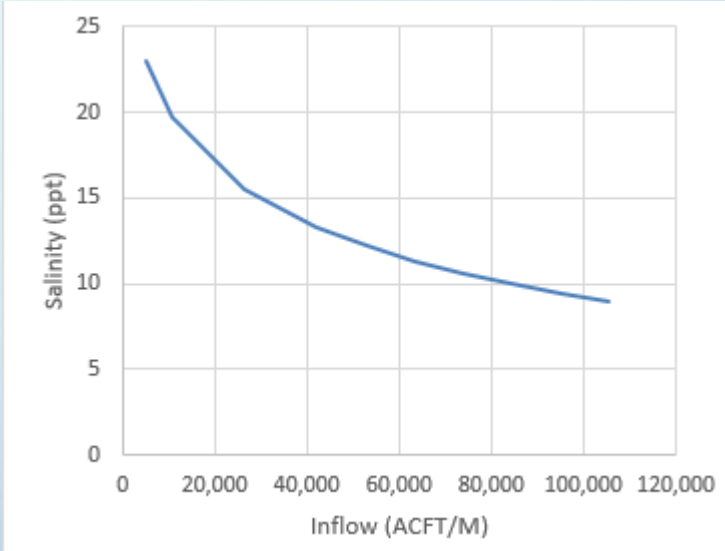


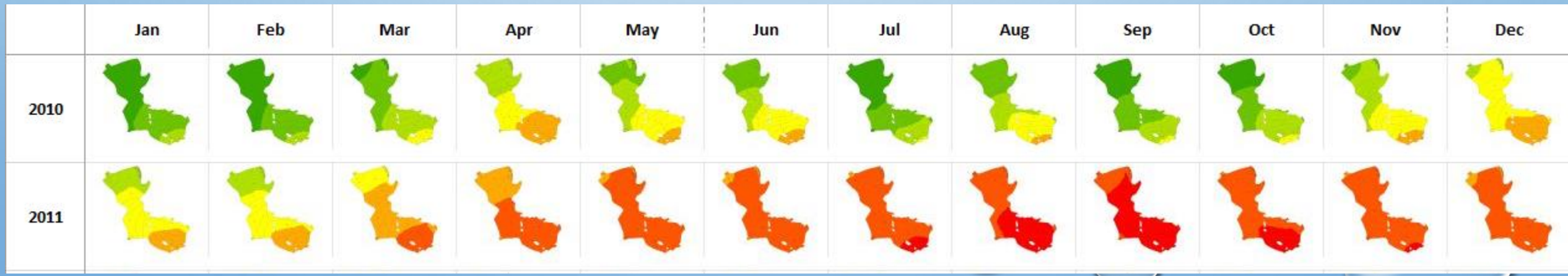
P = 0.5758



Some Results – Inflow/Salinity Standards







Very Preliminary Conclusions – Lavaca Bay

- Lavaca Bay is changing
  - Environmental
    - Lower inflow is leading to saltier conditions
    - Higher temperatures leading to lower dissolved oxygen
  - Biology
    - Benthic fish and invertebrates are crashing
    - Some species (like sea trout and black drum) like it
- Long-term climate change and freshwater diversion could be causing declines in water quality

GSA BBASC Work Plan Needs

- Guadalupe Estuary Specific
  - Tier 1 Priorities:
    - Priority 1 Life Cycle Habitat & Salinity Studies for Key Faunal Species
    - Priority 3 Rangia Clam Investigations
  - Tier 3 Priorities:
    - Nutrient Load & Concentration Monitoring

Importance of Long-Term Research*

- Provides a unique perspective on environmental processes, dynamics of populations and communities of organisms
- Ecological relationships can be obscured in short term studies by common features such as time lags, natural variability, nonlinear relationships, interactive drivers, or relatively slow processes
- Led to major scientific discoveries

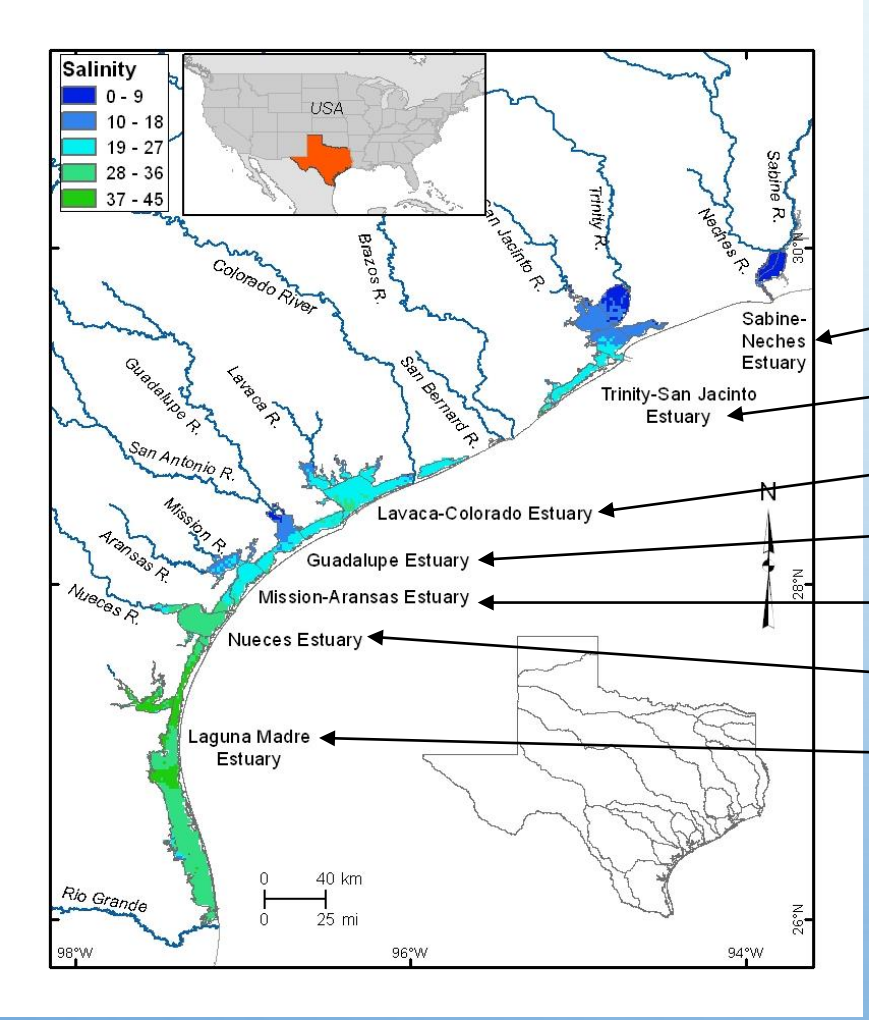
*Source: Hampton et al. *Limnol. Oceanogr.* 64:S2-S10 (2019)

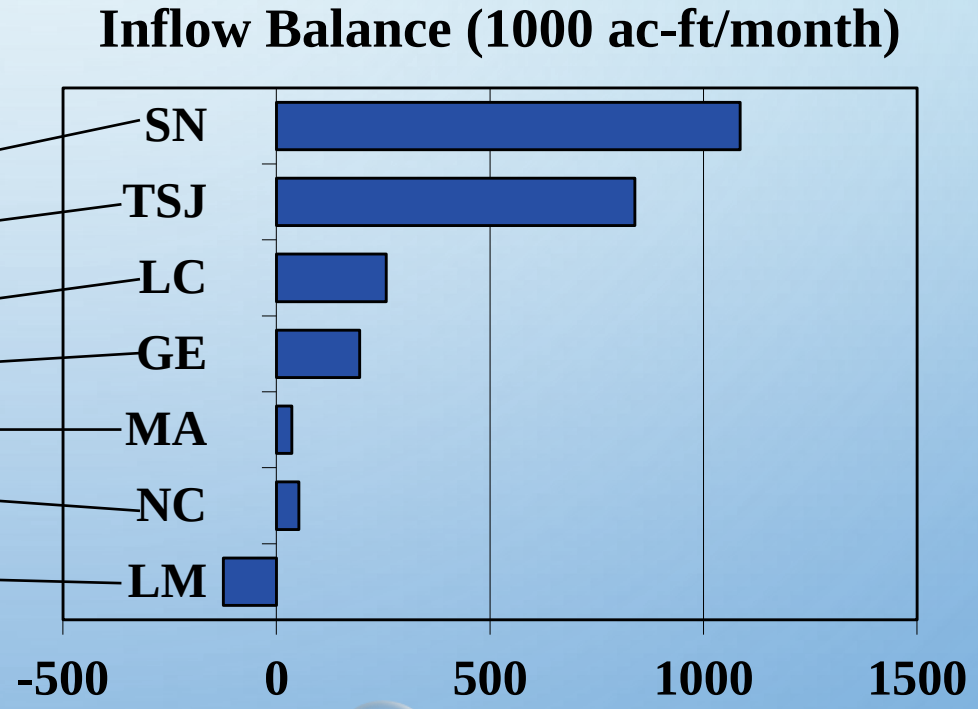
Maintained the Long-Term Program Via Synergies

- First TWDB studies began in 1987 with focus on San Antonio Bay
- Many synergistic projects since then:
  - Federal = EPA, NASA, NOAA, NFWF, NSF, USGS
  - State = TARP, TRDF, TCEQ, TGLO, TPWD, TXSG
  - Other = CBBEP, CCBNEP, LCRA, Private Foundations (3)
- Current Projects Ending in August 2019:
  - NOAA – "The Hydrological Switch: A Novel Mechanism Explains Eutrophication and Acidification of Estuaries"
  - NSF – "RAPID: Capturing the Signature of Hurricane Harvey on Texas Coastal Lagoons"

Importance of the Comparative Approach

Texas Coast-wide Inflow Gradient Provides a Perfect Natural Experiment



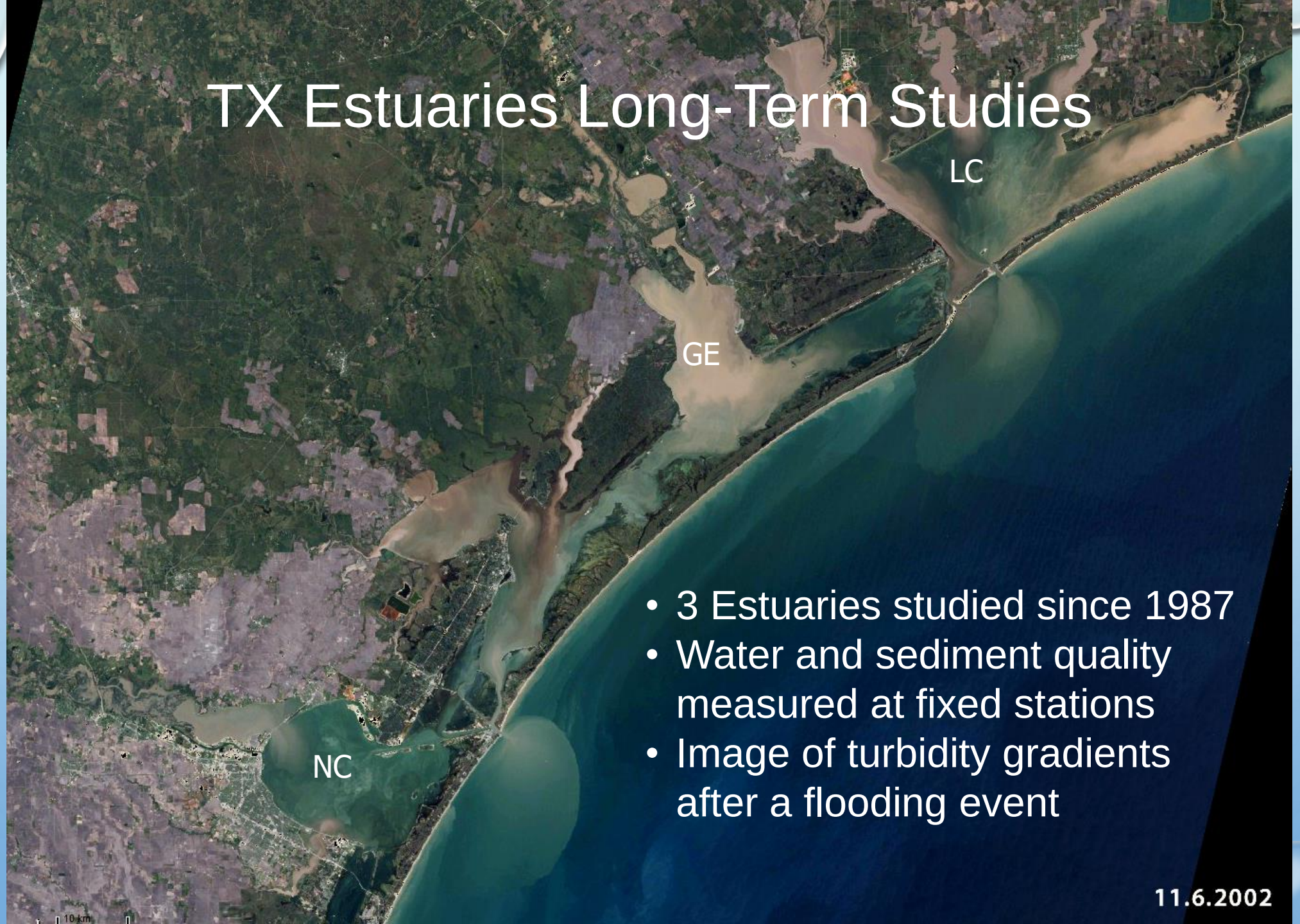


Inflow (TWDB): 1941-2009
Salinity (TPWD): 1977-2015

2. Long-Term Analysis in 3 basins

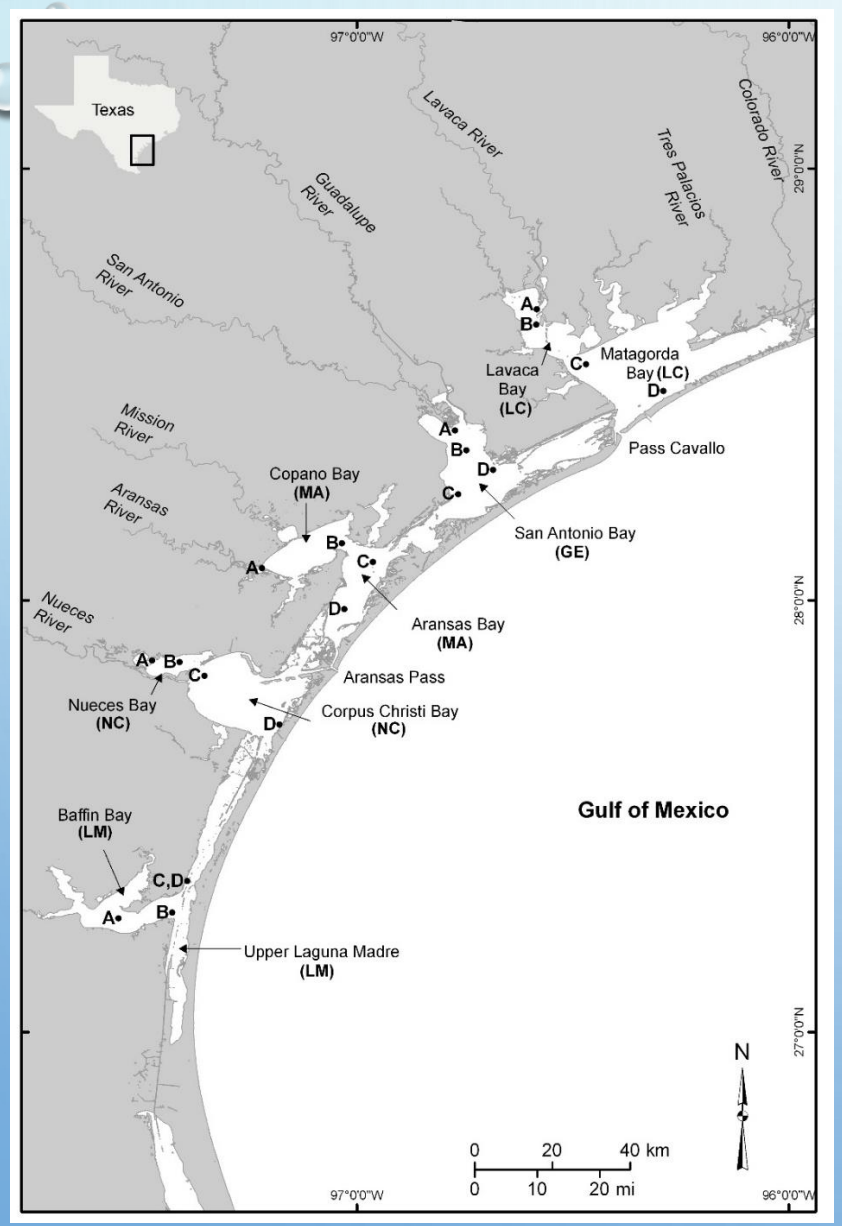
- Complete analyses of long-term benthic archive samples to evaluate the adequacy of the freshwater inflow standards adopted as part of the Senate Bill 3 adaptive management process
- Support 3 Basin and Bay Area Stakeholders Committees (BBASC) :
  - CL (Colorado and Lavaca Rivers and Matagorda and Lavaca Bays) BBASC
  - GSA (Guadalupe, San Antonio, Mission, & Aransas Rivers and Mission, Copano, Aransas, & San Antonio Bays) BBASC
  - NCC (Nueces River and Corpus Christi and Baffin Bays) BBASC
- Draft Final Report October 30, 2019 and Final Report December 31, 2019

TX Estuaries Long-Term Studies

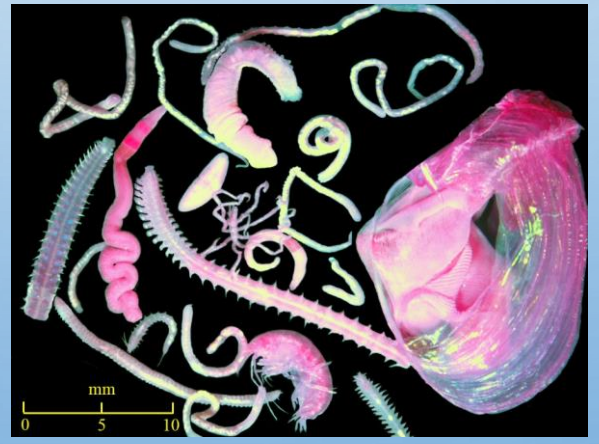


- 3 Estuaries studied since 1987
- Water and sediment quality measured at fixed stations
- Image of turbidity gradients after a flooding event

Benthic/FWI Long-term Studies (1986-2019)



- Climatic, across estuary gradient
  - 2 Positive Estuaries = LC and GE
  - 2 Neutral Estuaries = MA and NC
  - 1 Negative Estuary = LM
- Inflow, within estuary gradient
  - Secondary bay with two stations
  - Primary bay with two stations



Inflow Drives Estuary Conditions

LIMNOLOGY and OCEANOGRAPHY

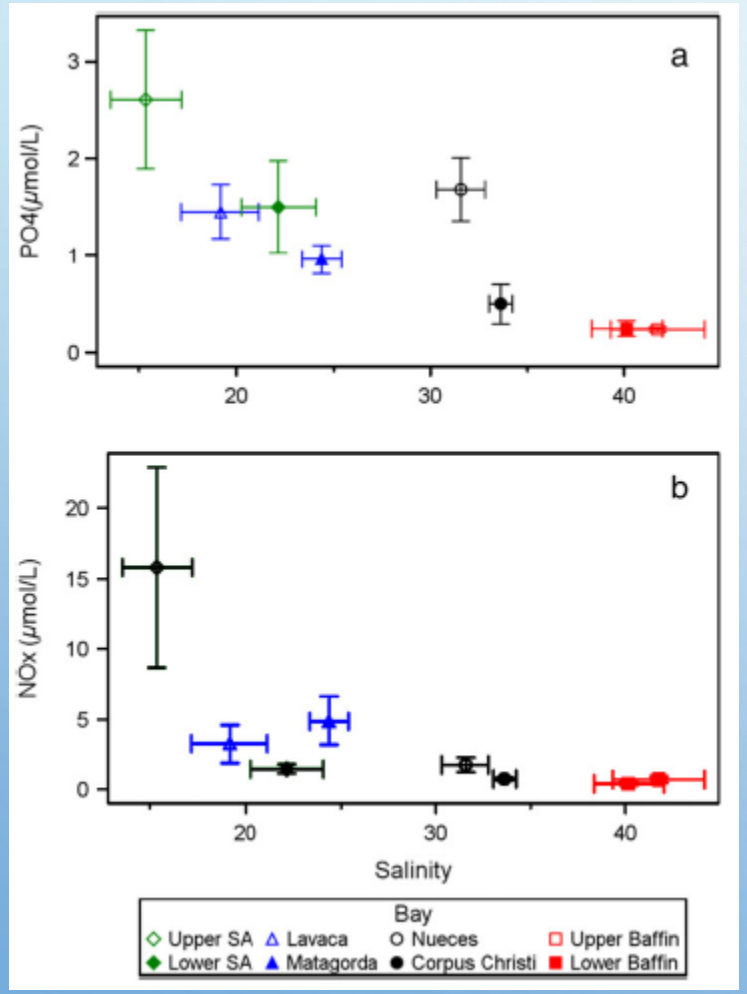
ASLO

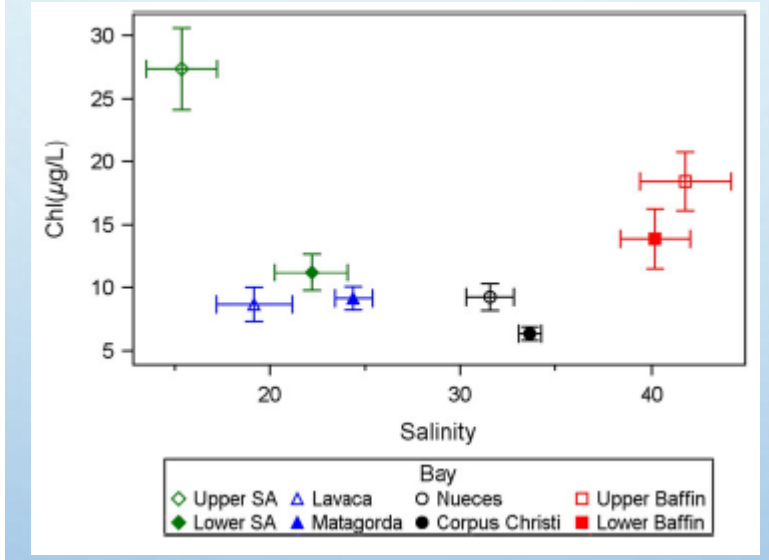
Limnol. Oceanogr
© 2018 Association for the Sciences of Limnology and Oceanography
doi: 10.1002/lno.10953

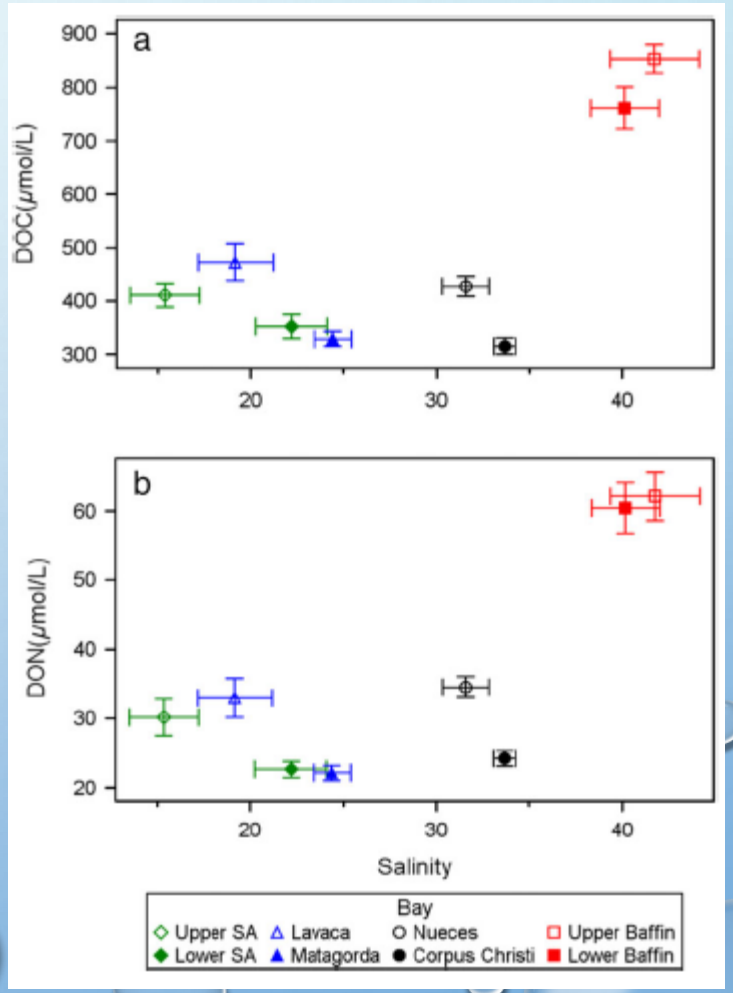
Effect of hydrological variability on the biogeochemistry of estuaries across a regional climatic gradient

Paul A. Montagna [1]* Xinping Hu [2] Terence A. Palmer,[1] Michael Wetz[3]

[1]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, Texas
[2]Department of Physical and Environmental Sciences, Texas A&M University-Corpus Christi, Corpus Christi, Texas
[3]Department of Life Sciences, Texas A&M University-Corpus Christi, Corpus Christi, Texas







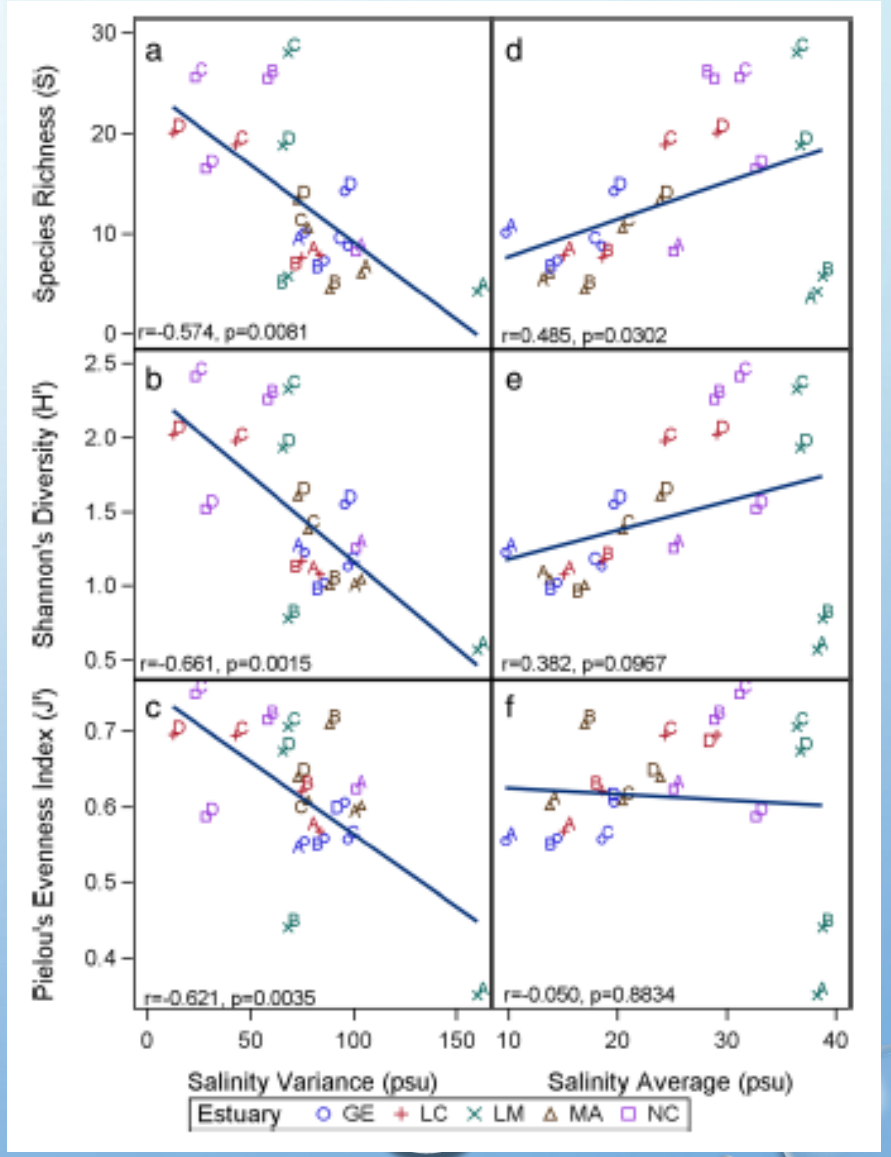
Salinity Variability Drives Integrity

Estuaries and Coasts (2016) 39:967–980
DOI 10.1007/s12237-015-0058-9

Is Salinity Variability a Benthic Disturbance in Estuaries?

Amanda D. Van Diggelen[1,2] · Paul A. Montagna[1]

- Salinity variance is more important that salinity average for determining benthic response



Hydrobiologia (2015) 753:111–129
DOI 10.1007/s10750-015-2200-x

PRIMARY RESEARCH PAPER

Impacts of droughts and low flows on estuarine water quality and benthic fauna

Terence A. Palmer · Paul A. Montagna

Effects of Droughts in 8 Texas Bays

Blue Crabs

- Abundance ↓
- Size (width) ↑
- Juvenile Abundance ↓
- Juvenile % ↔

Shrimp

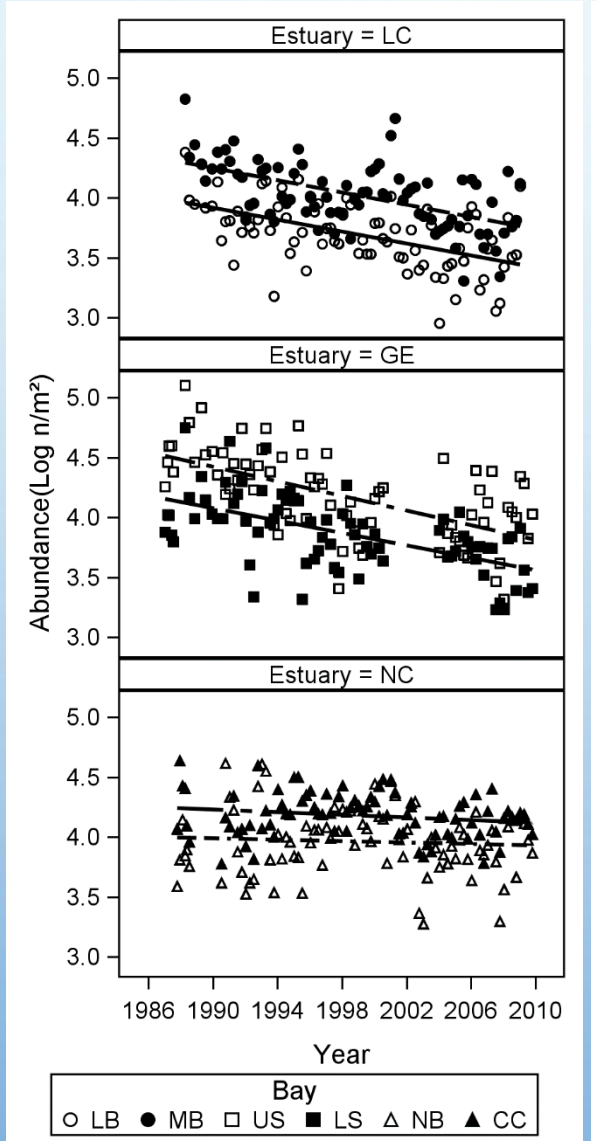
- Abundance ↓
- Size (length) ↑
- Juvenile Abundance ↓
- Juvenile % ↓

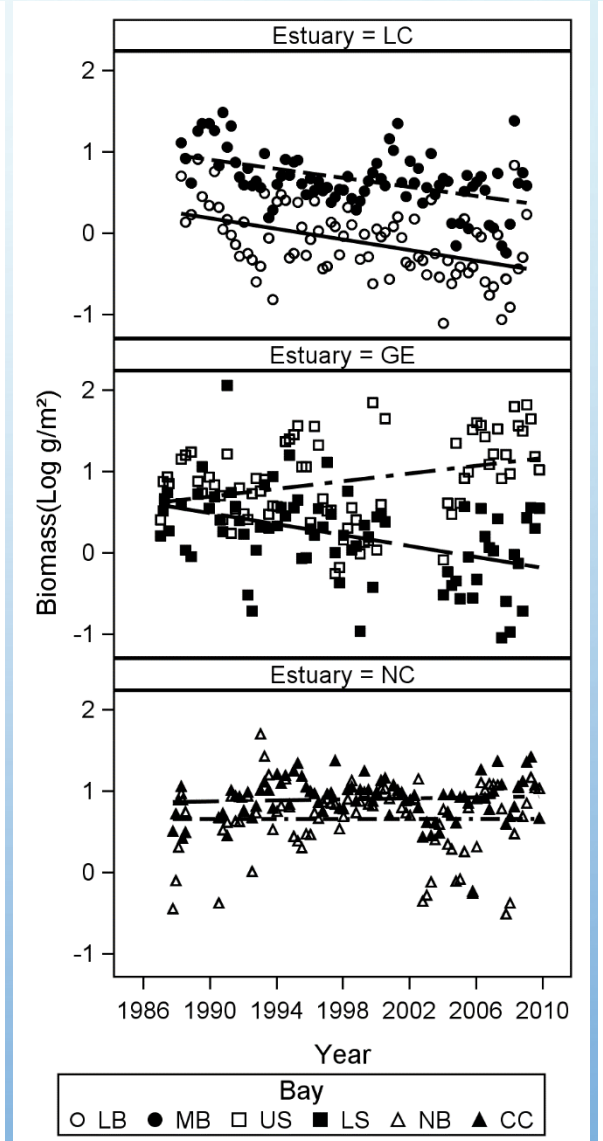
Water Quality

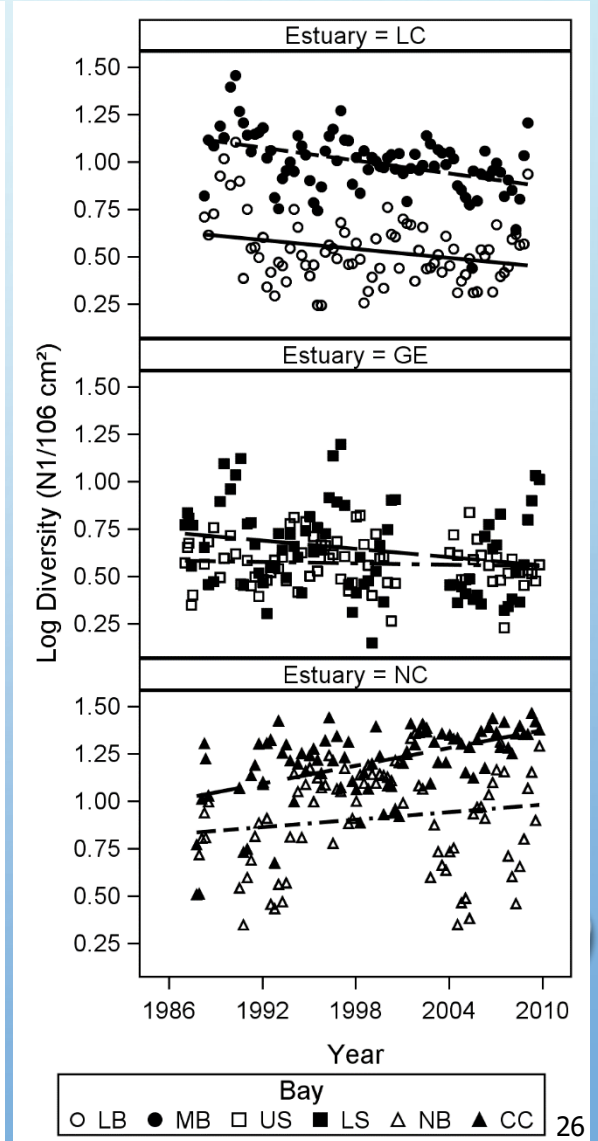
- Nitrate + Nitrite ↓
  Reduced loading
- Chlorophyll ↓
  Reduced nutrients
- pH ↓
  Reduced photosynthesis

Current Discoveries – Benthos are Declining Everywhere Except Upper San Antonio Bay

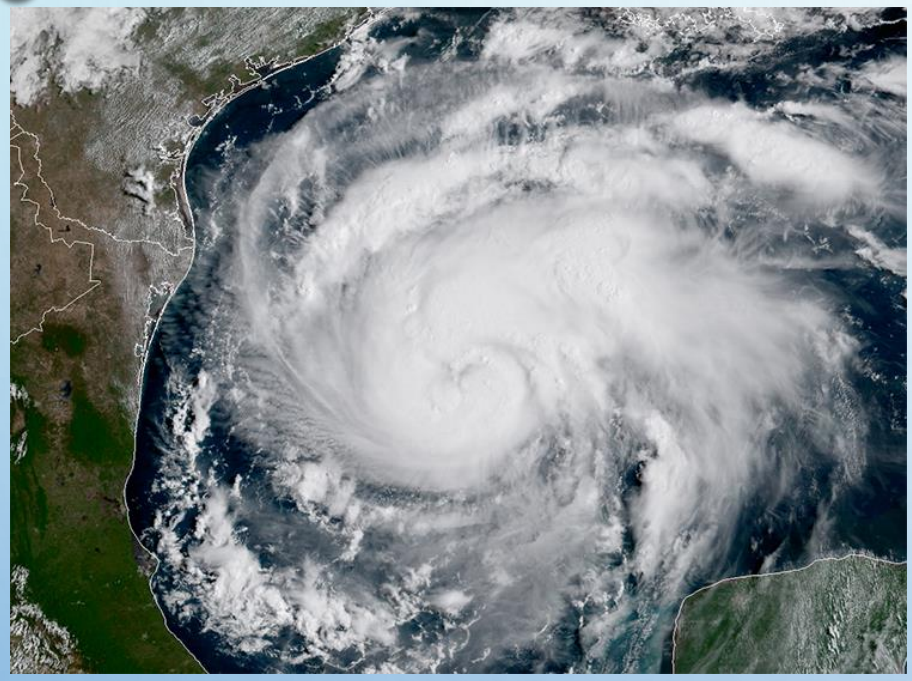
Metric \ Est	LC	GE	NC
Abundance	↓	↓	↓
Biomass	↓	↓↑	↔
Diversity	↓	↓	↑

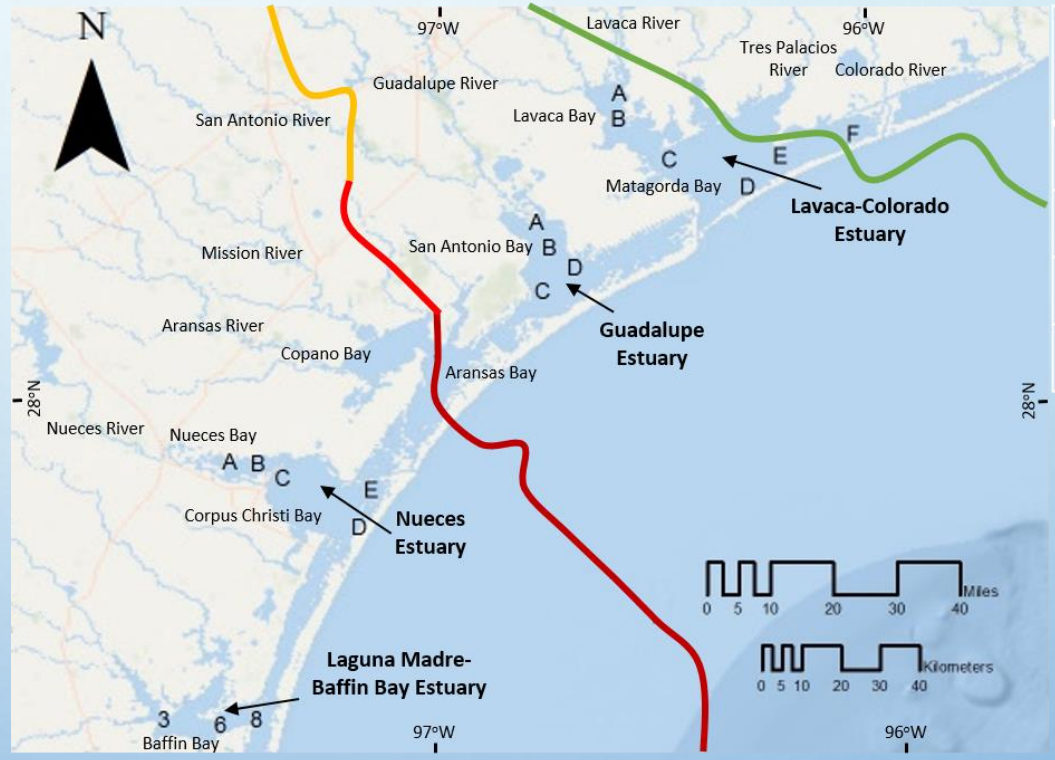






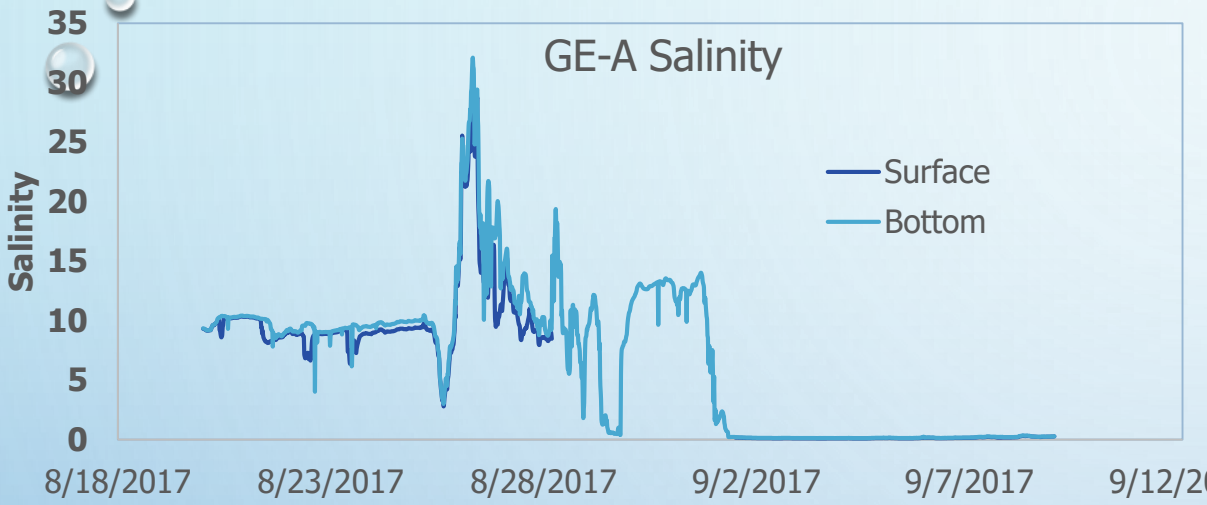
Hurricane Harvey – Short-Term View

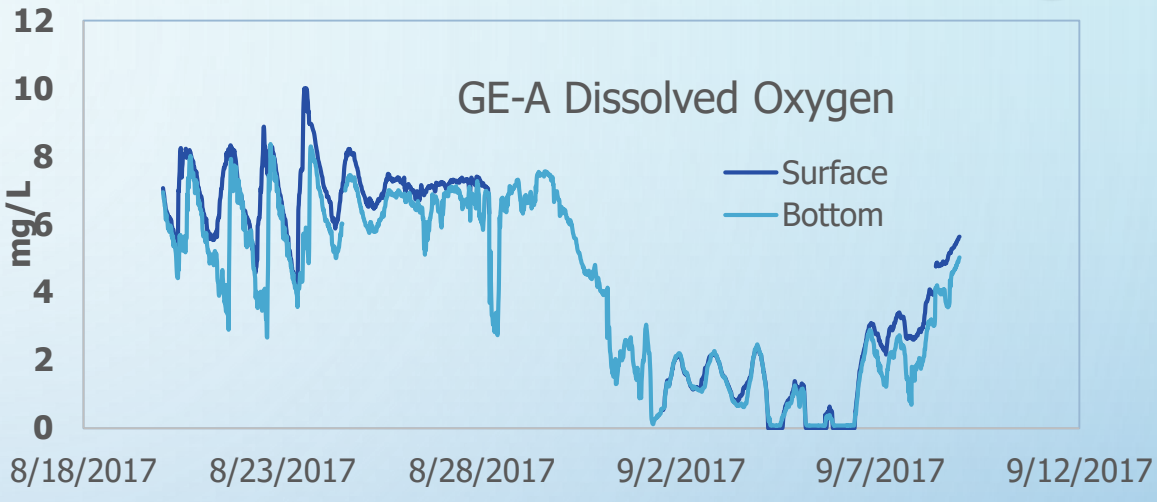




Color	Wind Speed (MPH)
	40 - 60
	80 - 100
	100 - 120
	>120

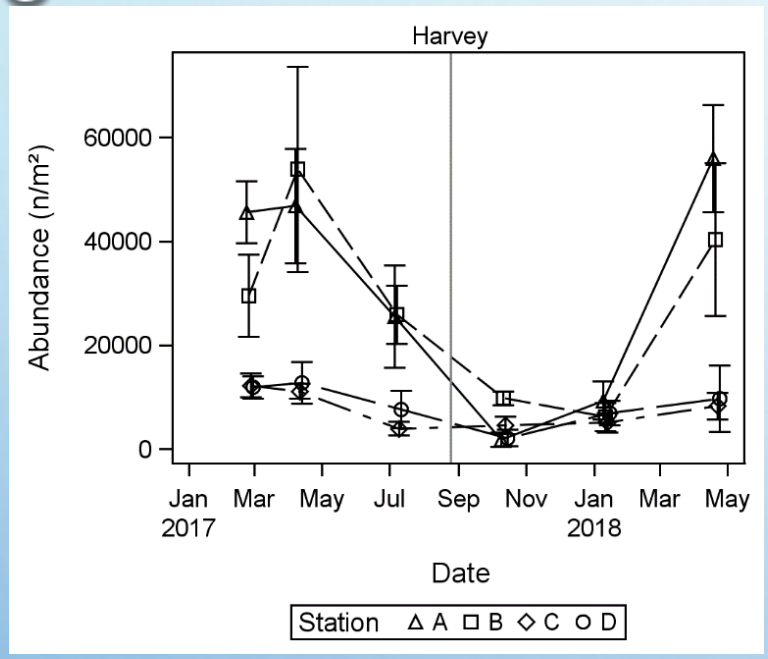
Hurricane Harvey – Short-Term View

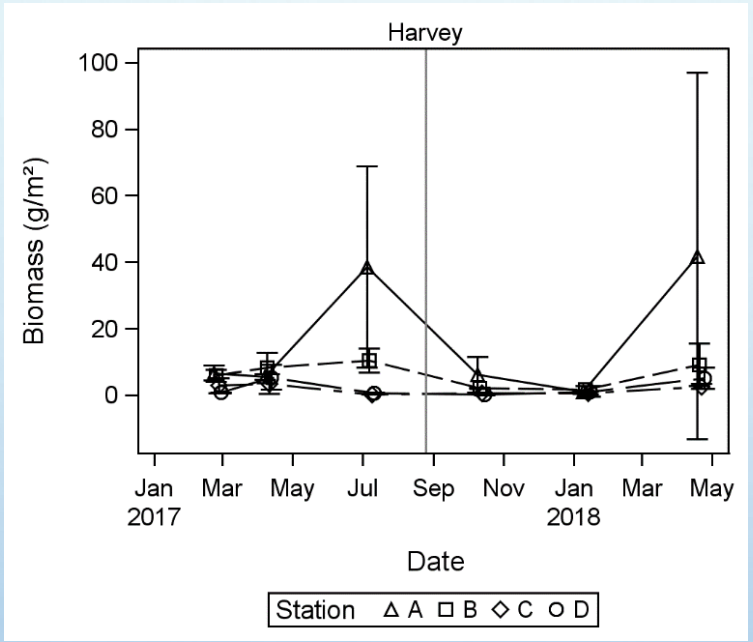


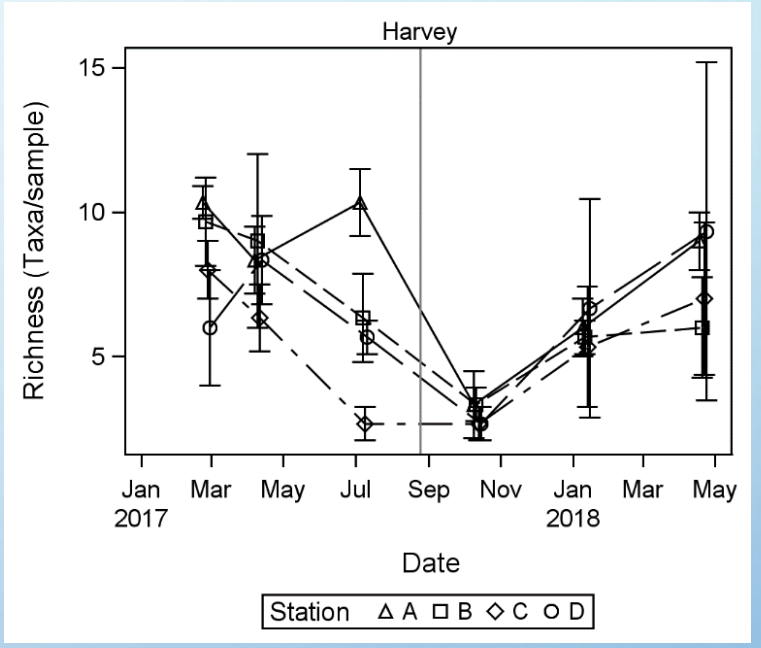


- It was a relatively average climatic period with salinity around 10 psu prior to the storm. As the storm approached, storm surge pushed salinities over 30 with in-rushing sea water. Salinities dropped as the storm passed and the rain swollen rivers began to flow. Salinity dropped to zero within 7 days of the storm.
- Once the rivers started to flow, nutrients and organic matter loading enhanced respiration of coastal blue carbon, and DO started to decline, reaching zero about 9 days after the storm. DO did not recover until 15 days after the storm.

Hurricane Harvey – Short-Term View

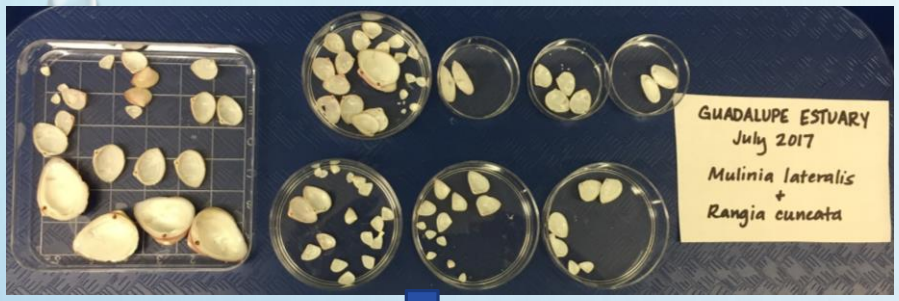


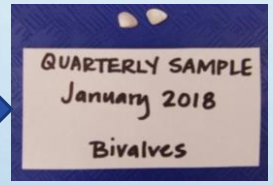




- The freshening and low DO caused a large decline in benthos abundance, biomass, diversity, and community structure changed

Hurricane Harvey – Short-Term View

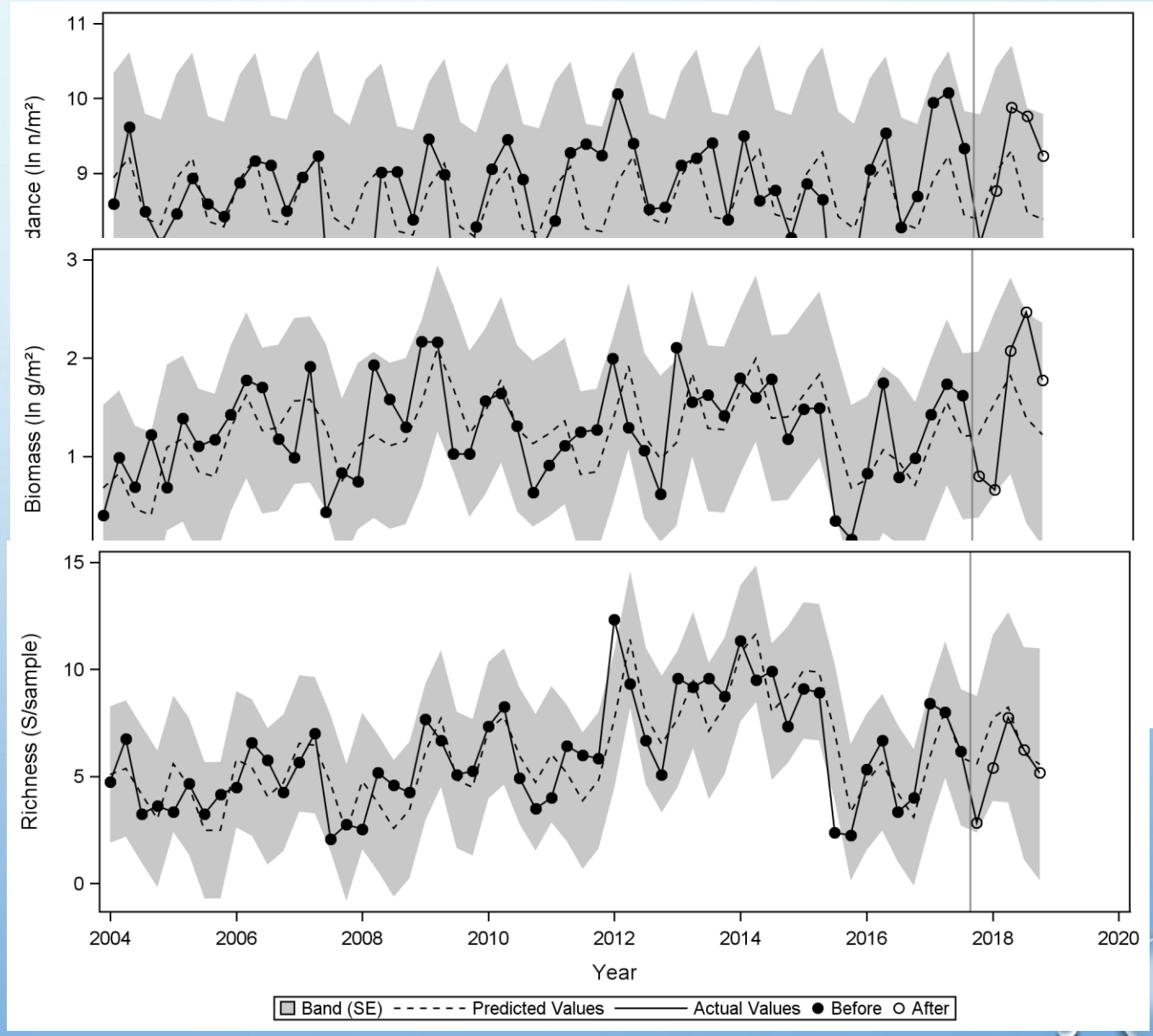




- The bivalves had an average abundance and size distribution prior to the storm.
- There was nearly nothing in the sediment for the first five months after the storm.
- There was a bloom of small *Mulinia lateralis* and *Rangia cuneata* by April 2018. These grew by July 2018, and a second bloom occurred.

Hurricane Harvey – Long-Term View

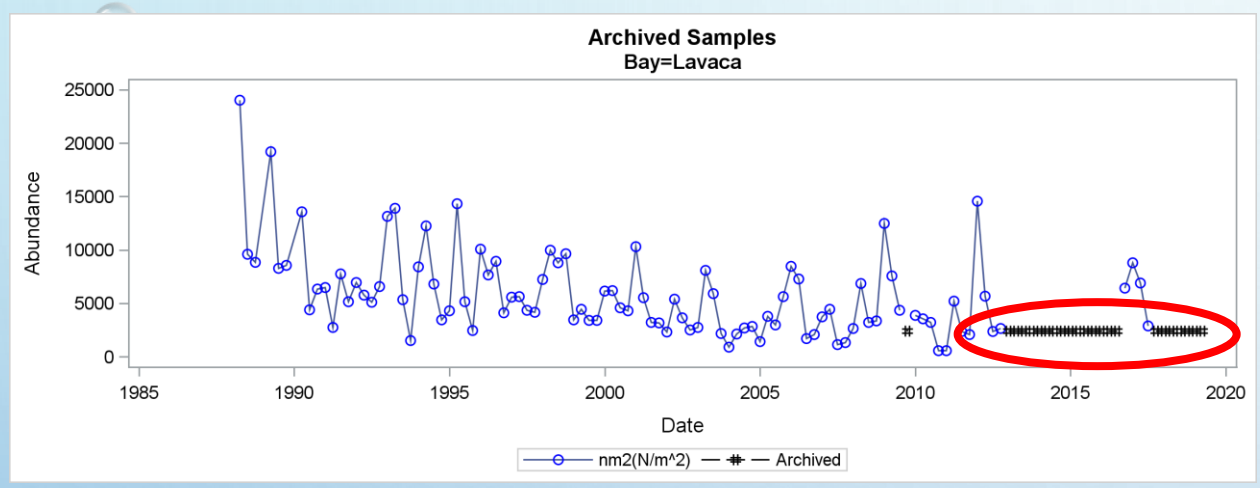
- Used a forecasting model to predict Oct2018-Jul2019 and compared to actual values
- Abundance would have went down anyway, recovery greater than expected
- Biomass would have went down but not as much, and spring bloom higher than expected
- Diversity went down more than expected, but recoved

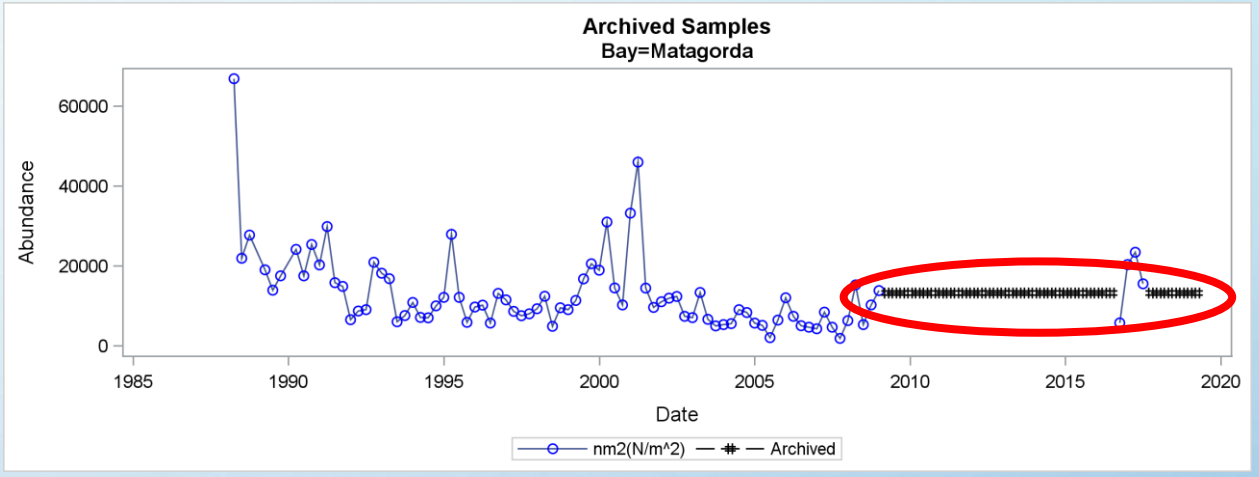


Very Preliminary Conclusions – Bay Comparisons

- We learn a lot more by comparing bays than looking at them individually
- We jump to the wrong conclusions by looking at the noise (over short terms) rather than the signal (over long terms)
- Salinity is an important driver:
  - Within estuaries along the salinity gradient
  - Among estuaries along the coastal climatic gradient
  - Over time: seasonally, year-to-year, and events

YOU CAN HELP – ASK FOR MORE LAVACA DATA





- I have a lot (314 to be exact) of un-analyzed, long-term samples from April 2009 to July 2016, and some post-Harvey samples
- I want to fill in the time series to answer some important questions:
  - Is the long-term decline still happening?
  - Did Lavaca Bay respond to Harvey like San Antonio Bay?

Questions?